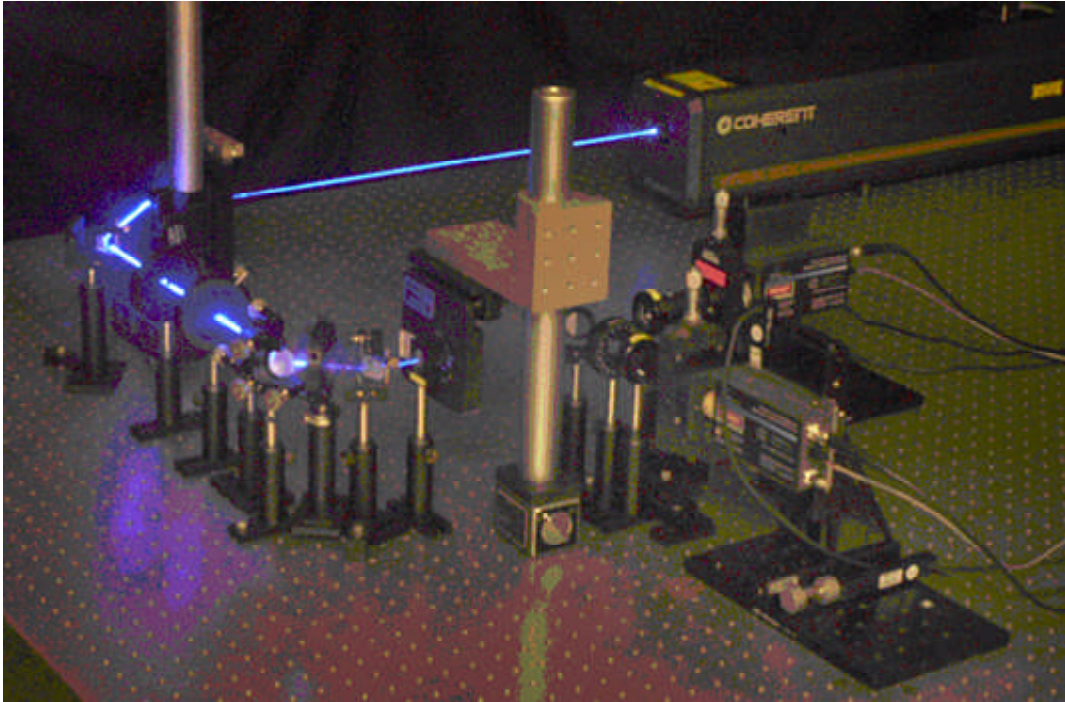


# Quantum Sensing and Communications Being Developed for Nanotechnology

An interdisciplinary quantum communications and sensing research effort has been underway at the NASA Glenn Research Center since the summer of 2000. Researchers in the Communications Technology, Instrumentation and Controls, and Propulsion and Turbomachinery Divisions have been working together to study and develop techniques that use the principle of quantum entanglement (QE). This work is supported principally by the Nanotechnology Base R&T program at Glenn. As applied to communications and sensing, QE is an emerging technology that holds promise as a new and innovative way to communicate faster and farther, and to sense, measure, and image environmental properties in ways that are not possible with existing technology.

Quantum entangled photons are "inseparable" as described by a wave function formalism. For two entangled photons, the term "inseparable" means that one cannot describe one photon without completely describing the other. This inseparability gives rise to what appears as "spooky," or nonintuitive, behavior because of the quantum nature of the process. For example, two entangled photons of lower energy can be created simultaneously from a single photon of higher energy in a process called spontaneous parametric down-conversion. Our research is focused on the use of polarization-entangled photons generated by passing a high-energy (blue) photon through a nonlinear beta barium borate crystal to generate two red photons that have orthogonal, but entangled, polarization states. Although the actual polarization state of any one photon is not known until it is measured, the act of measuring the polarization of one photon completely determines the polarization state of its twin because of entanglement. This unique relationship between the photons provides extra information about the system. For example, entanglement makes it easy to distinguish entangled photons from other photons impinging on a detector. For many other applications, ranging from quantum computation and information to quantum sensing, the entanglement property is critical.

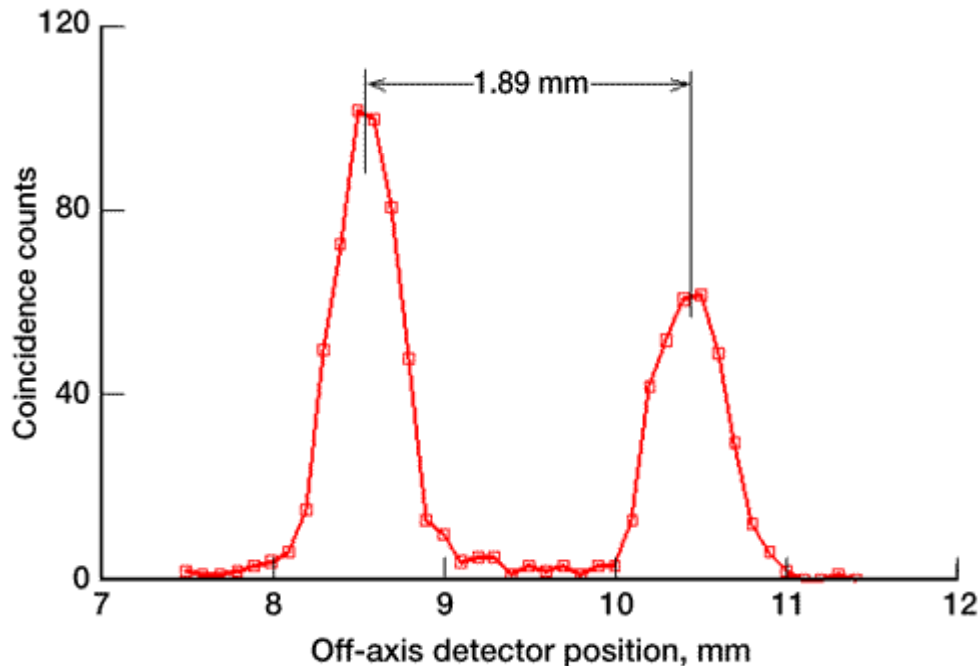


*Quantum entanglement setup. Glenn personnel used this setup to verify the presence of entangled photons in the system.*

Long description of figure 1 The setup in this photograph shows the minimal amount of optics required to produce quantum-entangled photons in the laboratory. Time-lapse photography and a beam illumination technique make the actual ultraviolet beam visible. The down-converted (red) light exists in single-photon quantities and cannot be seen even by the camera in the second half of the optical setup. Detectors at the end of the optical path collect and count the photons present at the detectors.

After the Quantum Communications and Sensing laboratory was completed, our first goal was to verify the presence of entangled photons. The optical setup for this experiment is shown in the preceding photograph. Once verification was complete, a technique known as the "quantum fax" was demonstrated. In this demonstration, an image of a double-slit pattern was "faxed" via a virtual quantum channel from one detector to another. In the demonstration, entangled red photon twins were sent down separate paths. One photon passed through a double slit, and the image of that slit was detected in the other photon (or "faxed") even though it never passed through a slit. Data from the quantum-faxed double-slit are shown in the following graph.

Finally, a comprehensive model of a nanocommunications system using entangled photons was computationally simulated with support from an Undergraduate Student Research Program student. The results showed clearly the feasibility and utility of using quantum-entangled photons for ultra-low-power space communications. High-resolution images can be transmitted over 100 km in free space if entangled photon pairs are used to represent uncoded 8-bit data symbols with less than 27 nW of total photon flux.



*Results of the quantum fax experiment. This graph shows an image that was "quantum faxed" using polarization-entangled photons.*

Long description of figure 2 The image of a double slit as experienced by one photon is imposed on the other photon that never goes through the slit. The entangled photon image obtained after coincidence gating shows a double-peak spacing of 1.89 millimeters. With a theoretical magnification of 2.5 times, the data predict that the real double slit has a spacing of 756 micrometers. The measured spacing of the real double slit is 750 plus or minus 25 micrometers, showing good agreement with theory. These data confirm that quantum entangled photons show a high level of momentum correlation. The single photon count was 3000 per second for the detector behind the double slit (a bucket detector) and about 300 per second for the (position-sensitive) scanning detector. The single photon counts remained relatively constant during the scan. Each point required 40 seconds to accumulate the coincidences shown.

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